Adapt: A framework for evaluating adaptation strategies

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ADAPT

A framework for evaluating adaptation strategies

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1.1 Introduction

The overall objective of the ADAPT project is to compare and trade-off different adaptation strategies for (1) protecting the environment, (2) improving food production and (3) developing industrial capacity in river basins –all under changing climate conditions. An innovative and challenging aspect is the comparison of adaptation strategies across river basins. The basins selected for the ADAPT project, however, are quite different in water resources characteristics, environmental controversies and socio economic issues. Hence, in order to evaluate a comparative study across these different basins, one uniform decision framework is needed.

The first question for developing such framework is: "For whom are we developing adaptation strategies?" It is proposed to aim at developing adaptation strategies for a basin manager or basin wide institution. In trans-boundary river basins, like some in the ADAPT project, this is often an imaginary institute or manager, since country or state borders often determine the jurisdiction of such policy bodies. These basins therefore lack the proper institutional arrangements that facilitate the development of *basin wide* policies. Similarly, other water resources policy studies are often restricted in their appraisal by country dependent legislation and therefore lack an integrated -basin wide- approach.

The second question is: "How are we going facilitate the integrated basin wide approach?" No doubt, a policy evaluation of adaptation strategies across both *geographically different* and *trans-boundary* basins will only succeed with help of a general assessment framework. Furthermore, a transparent decision framework will help raising awareness among decision makers of the choices available and helps to evaluate and compare the implications of these choices. It will also help providing information to the general public by ensuring transparency and accountability (WHO, 1996).

Although some basin areas are now in progress of establishing or developing a basin wide institute (e.g. International Commission for the Rhine, or Mekong River Commission), most basins completely lack such initiatives due to political sensitivities.

1.2 The DPSIR method

As stated above, there is a need for a general assessment framework, in order to arrive at some qualitative (and comparable) statement about the quality of the environment, the level of food production and the status of industrial capacity for the seven river basins. First, we need a method that allows for identifying what kind of environmental, food and industrial issues are dominant in the selected basins. And from there derive some quantitative indicators that show possible impacts of Climate Change / Climate Variability (CC/CV). Obviously, this is a very broad perspective and a restriction is being made such that only those issues are considered related to water resources. Yet, when comparing seven completely different basins, it can be expected that still a lot of issues will be relevant. For this, we need to somehow structure the variety of issues that relate to the state of the environmental system, the level of food production and industrial capacity (OECD 1994).

In this project, the decision framework for evaluating adaptation strategies will be based upon the DPSIR approach. DPSIR allows for structuring issues & problems in a basin and finally develop responsive adaptation strategies to cope with the impacts of CC/CV (see e.g. Ceroi 2002). The DPSIR approach was developed by the European Environment Agency EEA for indicator-based reporting on the environment (EEA 2002) and adopted by the OECD and EEA. The approach assumes cause-effect relationships between interacting components of social, economic and environmental systems.

Within this phase of ADAPT, we focus on environmental issues, food production and industrial capacity. Socio economic issues are only briefly touched within the industry component, and considered thoroughly in a second phase of the project. The components of the cause-effect relations of those three systems (Environment, Food, Industry) are: **D**riving forces, the **P**ressures resulting from the driving forces, The **S**tate of the system, the **I**mpact on the three systems and the **R**esponse of society (which creates new drivers for the system).

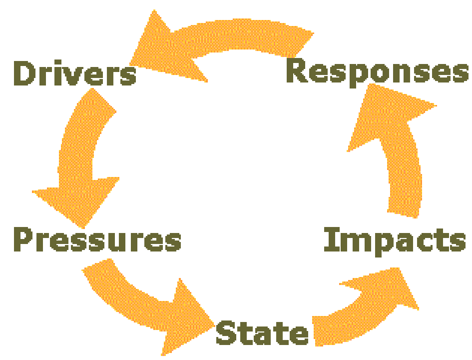

Figure 1.1 The DPSIR chain of cause-effect relationships.

The DPSIR approach (EEA, 1994) can be divided into five parts (Figures 1.1 and 1.2).

1. *Identification of drivers*, such as population growth, economic growth and climate change. Combinations of those are treated as 'scenarios' in the ADAPT project.
2. *Identification of pressures*, which are activities (with often a negative impact) resulting from the influence of the drivers. Most commonly, pressures are very much related to 'issues and problems' related to water resources in a river basin.
3. *The state of water resources system.* The current state of the water resources in a river basin is expressed in terms of (proxi-) indicators. Each of those indicators quantitatively measures the state of the water system with respect to the three aforementioned goals (maximizing Environmental quality, Food production and Industrial capacity).
4. *Impacts.* Those are state *changes* that can be measured by evaluating the values of the indicators under different climate change / variability (CC/CV) and economic / population growth scenarios.
5. *Response by developing adaptation strategies*. Here we may define possible adaptation strategies that will be evaluated on their capability to adverse negative impacts

on the water resources system due to CC/CV and exploit the positive impacts due to CC/CV.

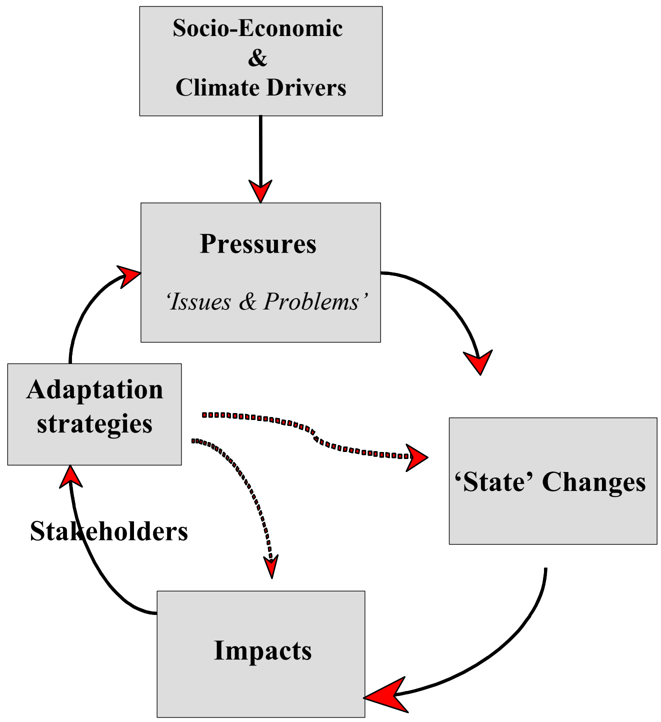

Figure 1.2 *DPSIR approach with drives, pressures, state changes, impacts and responses. Within ADAPT, responses refer to 'adaptation strategies'.*

2. The decision framework

2.1 Drivers

Driving force, as defined within the DPSIR approach, describes the social, demographic and economic developments in societies and the corresponding changes in life styles, overall levels of consumption and production patterns. Primary driving forces are population growth and developments in the needs and activities of individuals, but also change in climate conditions due to expected climate change (CC) and climate variability (CV). These primary driving forces provoke changes in the overall levels of production and consumption, and hence exert pressures on the environment, food production and industrial capacity (EEA 2002). Other driving forces are, for example, land use change, intensification of agriculture and global economic development.

ADAPT: For the ADAPT project, driving forces are defined as *exogenous drivers* that influence the environment, food production and industrial capacity related to the water resources system of a river basin. Hence driving forces cannot be influenced by policy or adaptation measures on a basin scale. For ADAPT, the driving forces are defined as a combination of climate change and variability scenarios, population growth scenarios, economic growth scenarios and accordingly to the latter two, changes in food consumption rates. We will use the latest IPCC scenarios SRES A2 and B2 for two different time periods: 2010-2039 and 2070-2099.

2.2 Pressures

Pressures describe developments in physical and biological agents, the use of resources and the use of land by human activities under the influence of the above-described drivers. The pressures exerted by society are transported and transformed in a variety of natural processes. They manifest themselves in changes in environmental conditions, changes in food production and changes in industrial capacity. Some of the pressures are conversion of land, waste disposal in rivers and coastal waters and water abstraction.

ADAPT: Within the ADAPT project pressures relate to ‘issues and problems’ of water resources management in a river basin. They arise from the drivers, which in particularly refer to changes in climate and climate variability.

2.3 State indicators

State indicators allow for the quantification of different goals of a decision maker (in the case of ADAPT: maximizing Environmental quality, Food production and Industrial capacity). The aim is to derive a set of indicators that is comprehensible but at the same time reflects all aspects of the water resources system (related to environment, food and industry). We use indicators to simplify the data and to make it more comprehensible. Indicators allow for following state changes in time.

An indicator has to meet a couple of criteria, in order to make it operational: (1) An indicator has to be representative with respect to the goal it represents, (2) it must be flexible to use and understandable for all stakeholders and users involved in using the framework and (3) the data needed to measure an indicator must available. Finally, (4) indicators must be generally comparable across the different basins and cover the most important dimensions and issues of concern of the basins (Cole, 1998).

The whole indicator set must be comprehensible in order to for two reasons. Firstly, to simplify the communication process between stakeholders involved in evaluating adaptation strategies. And secondly, to allow a comparison of adaptation strategies across very different basins ('more indicators means a more complex comparison').

ADAPT: In the case of ADAPT, The indicator values need to provide information about or describe the state of the environment, food production and industrial capacity -- although these issues largely differ across the basins. This means that some indicators do only apply for specific basins, whilst some indicators apply for all basins (OECD 1994).

2.3.1 Environmental quality indicators

We here envision environmental quality as a prerequisite for providing environmental services to both humans and ecosystems. Humans are living in and using the environment, the latter for instance, by using drinking water. An ecosystem can only be self-sustaining if all environmental processes are in balance, and hence will be disturbed if for example water quality is deteriorating. Hence, water quality is directly influencing humans and ecosystems (see figure 3).

Environment in a river basin is often seen as the equivalent of water quality. But other issues play a role, such as biodiversity and structure of ecosystems and the security of humans to be protected from floods. To get a good overall view of the different aspects of the environment, we define two environmental categories that are linked to the central theme 'water' and that can be optimized by a manager by taking the proper –adaptation-measures. The categories are a 'human environmental' category and an 'ecosystem' category.

The *human environment* is subdivided in human health and security We confine ourselves to some first order effects on humans because otherwise we might get stuck in the socio-economic side of environment(al change), which is not considered in this phase of the project. Security is broadly defined as the number of people at risk as a result of flooding. Health can be further divided in the risk of eating contaminated fish and the direct effect of water quality such safe drinking water and safe water for bathing.

The *ecosystem* side is often equated with ecological quality, which is here elaborated in terms of two ecosystem characteristics: Habitat and Water quality. This elaboration is based on a literature survey of such concepts as ecosystem health, ecological integrity, and biodiversity (Lorenz, 1999). It is argued that an ecosystem is functioning well when its processes (e.g. nutrient cycling expressed in water quality) are performing optimally, and its habitat (expressed in structure, area and biodiversity) is optimal as well.

Ecosystem resilience may be added to habitat and water quality, but our experience has shown that this is not always useful. Resilience is perhaps better seen as operating at a different scale, and even to be a direct or indirect product of optimal process and structure.

The above-mentioned environmental categories are presented in Figure 2.1, a so-called 'decision tree'. At the top, a box represents the overall environmental quality of the river basin, which must be optimized under changing climate conditions. This divided in a lower level with a human and an ecosystem environment. Next, the sub-categories (health, security, habitat and water quality) are identified, which can be measured by indicators. They, thus specify the state of each sub-category.

Box 2.1 describes each environmental indicator. Note again, that some indicators only apply for specific basins. Environmental indicators include, for instance, number of species, water quality, water quantity, etc. A feature of these indicators is that they can be derived from simulated data from models or can be quantified by experts. Also, some indicators are more important than others. For example, BOD is less important in terms of environmental impacts as compared to fertilizers. Fertilizers are important as an indicator for the difference between intensive agriculture and extensive agriculture and hence can be used to trade off food adaptation strategies against environmental adaptation strategies.

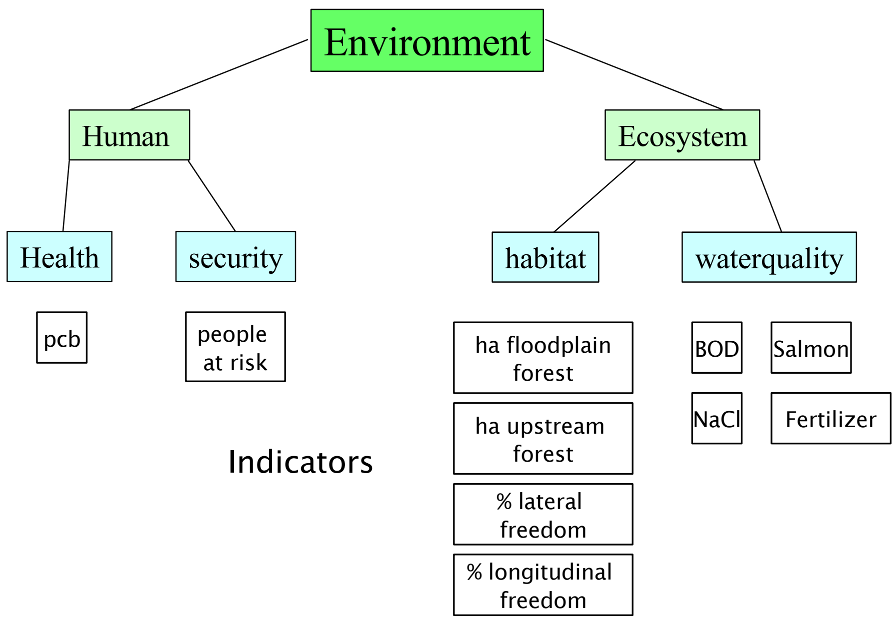

Figure 2.1 Decision tree for Environmental Quality. On top, the goal ('improve Environmental quality'), further sub-divided into two categories (Human environment and Ecosystems) and finally going down to measurable indicators.

Within the ADAPT project, we do not included analyses by means of water quality models, as well as we do not quantitatively derive structural habitat impacts. Hence, most impacts must be quantified using expert knowledge using ordinal scales using '+' and '-'.

Box 2.1 Explanation of environmental indicators.

HUMAN ENVIRONMENTAL INDICATORS	
# people at risk:	This indicates the number of people that at risk to floods in the floodplains under changing climate and how the different adaptation strategies influences this number. The number covers people that could be injured or killed when a flood occurs.
PCB	This indicator measures the concentration of pollutants like pesticides and industrial by-products. PCB is an example of these pollutants and is a chronic pollutant. Concentrations of such contaminants in fish give an indication of the concentration of these pollutants in water and aquatic soil. These pollutants are obviously bad for human health. The most occurring pollutants in the ADAPT basins are PCB, DDT, mercury, lead, dioxin, other heavy metals and pesticides. These chemicals bind on fat and accumulate in the food chain. Other fish species can be used as indicator. For instance, for The Rhine the species 'Eel' is used.
ECOSYSTEM RELATED ENVIRONMENTAL INDICATORS	
# Salmon	This is a bio-indicator for water quality. The fish needs a certain minimal quality of water and quality of habitat (geomorphologic) to be able to survive and reproduce in a river system. If the fish is able to survive, the overall quality of the system and water quality is good. Instead of salmon or stout any other fish can be taken.
ha upstream forest	The area of forest in the basin is an indicator for the size of the ecosystem habitat forest. It also tells something about the pristinity of the area and indirectly explains changes in erosion rates and sediment loads.
ha floodplain forest	The area of floodplain forest or mangroves (in ha's) is an indication for the size of this habitat and this is a condition for biodiversity. It also tells something about the pristinity of the river delta.
ha wetlands	The area of wetlands is an indicator for the size of this habitat and it measures indirectly biodiversity of the area.
[ ] BOD	Biochemical Oxygen Demand concentration. This measures the amount of oxygen required or consumed for the microbiological decomposition of organic material. It indicates how much organic matter is discharged by human activities. The BOD is lowered when sewage treatment plants are constructed. High BOD levels generally indicate low water quality.
[ ] NaCl	The concentration of NaCl in the river will increase when the sea level rises and when the fresh water flow of the river decreases. It may disturb the freshwater habitats, reduces food production and endangers surface drinking water facilities. It is best to choose a representative station downstream in a place, which lies in areas where salinization occurs. It is possible to value on the ordinal scale when no conductivity data is available.
Fertiliser	The concentration of P of N in water is an indication of eutrofication by fertilisers.
% Lateral freedom	This indicator provides the percentage of the river area, which is not protected by man made dikes. The higher this percentage, the less dikes or protective measures have been applied, and hence the more natural (pristine) the river is. More dikes generally protect the river from flooding but prevents exchange of nutrients and fish to the flood plains. This influences biodiversity negatively. Decrease in lateral freedom also influences the flood dynamics of the river basin, and hence the ecosystem equilibrium.
Longitudinal freedom	Number of dams and barrages in the river. Here we mean man-made obstructions that hinder fish migration, and hence lower biodiversity and ecological quality. . Decrease in longitudinal freedom also influences the flood dynamics of the river basin, and hence the ecosystem equilibrium.

2.3.2 Food indicators

In the same way as described for environmental state indicators in Paragraph 2.3.1, the state indicators for food are derived in a couple of steps. First, we may divide Water & Food related issues in the projected quantity of food produced and the security of food production in the future (within ADAPT we confine ourselves to the time periods 2010-2040 and 2070-2100). In summary, the overall goal of a basin manager would be to enhance food production quantity and security for these periods under climate change and variability. These goals are often referred to as the chance on crop failure. Different indicators can measure both quantity and security; these are mentioned in Figure 2.2 and Box 2.2.

The set of food indicators presented here is limited but gives in an integrated way an overview of the performance of agriculture (irrigated and rained) for different scales. Note that the variation across assessment parameters can be defined in terms of spatial variation (between farmers) or as temporal variation (between years).

In contrast to the previous environmental section, ADAPT uses food simulation models, which are capable of directly calculating values for the food related indicators for the current situation as well as for the future.

The indicators from Box 2.2 relate to the dominant crops of the basin, so they are different for each basin.

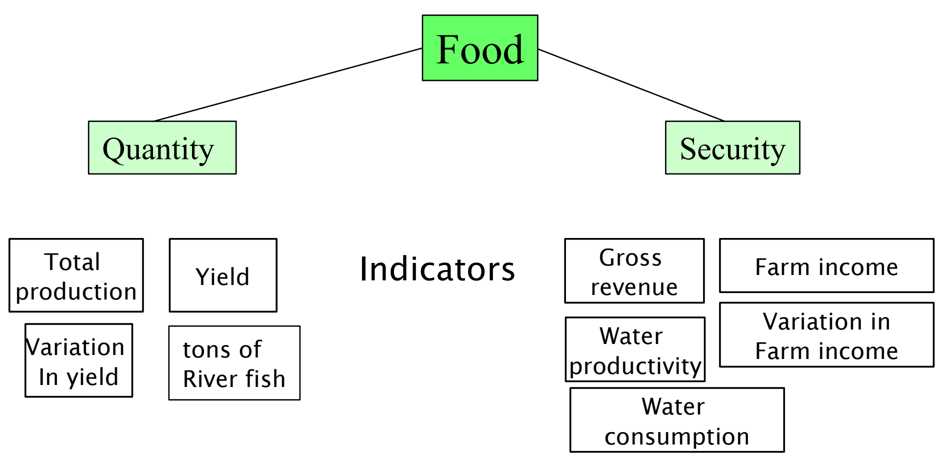

Figure 2.2 Decision framework for 'Enhancing and preserving food production'.

Box 2.2 Explanation of food indicators.

FOOD PRODUCTION (QUANTITY)
- Total production (kg)
- Average yield (kg ha^{-1})
- Variation in yield (CV)
- Tons of fish (kg)

FOOD SECURITY
- Net revenue ($)
- Average farm income ($)
- Variation in farm income (CV)
- Water productivity ($ m^{-3})
- Water consumption of total water (MCM and %)

2.3.3 Classification of state indicators: Industry

Finally, the last goal for a basin manager related to the maintenance of water resources is to 'Enhance and preserve Industrial capacity'. In this study, Industrial capacity related to water resources is only a minor part in this project, but appears to be an important issue in both environmental and food issues. In many of the environmental controversies, Industrial capacity development (e.g. hydropower development') is traded of against environmental objectives. It is, therefore, taken as a separate goal in the overall analysis.

For 'Industrial capacity' we only focus on 'energy produced by hydropower' and 'transport capacity' of a river system. Both can be measured by different indicators, which are mentioned in Figure 2.3 and Box 2.3.

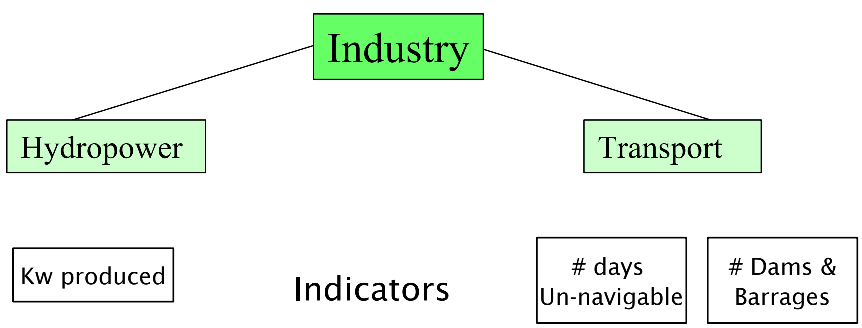

Figure 2.3 Decision framework for 'Enhancing and preserving 'Industrial capacity'.

Box 2.3 Explanation of Industry indicators.

KWatt produced:	This indicates the produced energy by the dams and reservoirs.
# of dams:	This indicates how great the disturbances for transport are in the river system (see also the environmental section).
# days un-navigable:	The river can be un-navigable because of either too much water or because of lack of water, this for the average sized ships. Changes in runoff may effect the number of days these extremes occur.

2.4 Impacts

Figure 2.4 shows a detailed processing scheme of the ‘Impacts’ box in the DPSIR approach The changes in the state of the water resources system due to the drivers, will lead to impacts on the environment, food production and industrial capacity. These changes can be negative as well as positive. Impacts are calculated by first calculating the current state of the water resources system and next calculating the future state of he water resources system (again using the same indicators) with and without climate change or other drivers.

Climate change and variability scenarios are derived from IPCC and cover periods of 2010-2039 and 2070-2099 respectively. We will, however, not dynamically evaluate changes in state indicator values over these whole periods, but compare the values of the state indicators at the end of both periods with the values of the state indicators in the current situation.

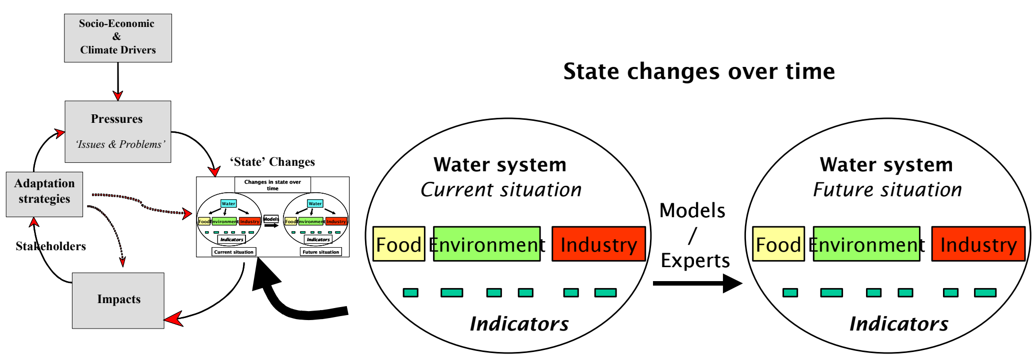

Figure 2.4 Detailed processing scheme of the ‘State changes’ box.

2.5 Adaptation strategies (‘response’)

The changes in the state of the water resources system will result in responses. Those responses may, for instance, refer to responses of the system itself (also referred to as ‘ecosystem resilience capacity’) or responses by organizations or society, which are here defined as ‘management responses and ‘policy responses’. A set of management response and measures to alleviate impacts of climate change and climate variability is referred to as an ‘Adaptation strategy’. Within ADAPT, we’ll focus on management options and policy options, from here referred to as ‘measures’. The location for developing adaptation strategies in the DPSIR chain is clearly presented in Figure 2.4.

2.5.1 Developing adaptation strategies

In the context of the ADAPT project (Water, Climate, Food and Environment under Climate Change) four different sets of adaptation strategies will be evaluated: Environment, Food, Industry, and Mixed. The idea behind these sets of adaptation strategies is that for each set emphasis will be put on one of these items, without losing reality. In other words, an environmental focused adaptation strategy does not imply that all water has to go to the environment, but only a realistic amount given minimum required allocations to other sectors. As an example, it will not be realistic to assume that the amount of water consumed for environmental security is so high that diversions to drinking water will fall below an acceptable level. Similarly, the food adaptation strategy does not imply that no water at all will be allocated to the environment. It is basin dependent to define each adaptation strategy as long as the four sets are clearly distinct but are still within realistic bounds.

As stated above, while all adaptation strategies aim at alleviating impacts of climate change and climate variability, each adaptation strategy favors a different issue (see Figure 2.5). The four strategies are:

- Adaptation strategy 1; Environmental adaptation (ANNEX 1);
- Adaptation strategy 2: Food security adaptation (ANNEX 2);
- Adaptation strategy 3: Industrial adaptation;
- Adaptation strategy 4: A mix of 1, 2 and 3.

The fourth adaptation strategy will be a mix of measures, where all the issues (environment, food, industry) will be taken into account. In this way, policymakers can gain insight in how different strategies affect the basin and the different activities.

An adaptation strategy comprises a set of management or policy measures. For instance, food security induced adaptation strategy to adverse impacts of climate change might comprise of several management measures, such as: ‘built a reservoir’, ‘shift irrigation patterns’ and ‘ensure transport in dry periods by new dams’

An important note is that the four adaptation strategies contain adaptation measures that may vary across in the different basins, and hence are specifically designed for each basin by the basin project groups. They will be based on available environmental impact Analysis reports, model results, expert knowledge, etc. Hence, they are only comparable at the level of the main issues (maximizing Environmental quality, maximizing Food production and maximizing Industrial capacity).

Figure 2.5 explains how each of the four adaptation strategies will be developed per basin on the basis of the measures available. The figure shows that, for instance, the environmental adaptation strategies for the Mekong comprises different measures as opposed to the Rhine and Volta basins. However, they all strive to cope with climate change and climate variability while protecting the environment.

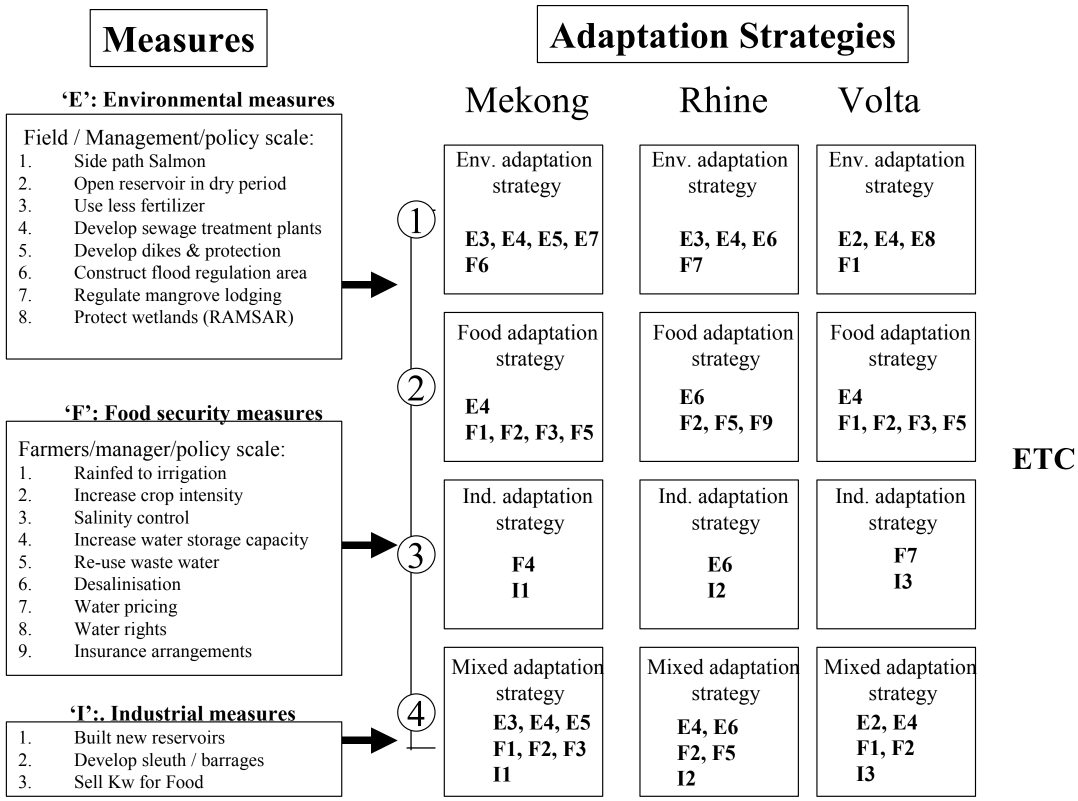

Figure 2.5 Developing Adaptation strategies: this figure explains how each of the four adaptation strategies per basin will be developed on the basis of an available set of measures.

Individual measures from which the adaptation strategies will be developed, are described in the next chapters.

2.5.2 Evaluation of adaptation strategies

Once the four adaptation strategies are developed, an evaluation will be conducted using the indicator set as explained above. All four strategies will be evaluated under different climate change scenario's (SRES A2 and B2) for two different years (2039 and 2099). Table 2.1 shows all comparisons within the evaluation. Note that the scenario runs comprising both '*with* adaptation strategies' and '*without* adaptation strategies' will be compared to a base line run ('the current situation').

Next, for each run, the (probably changed) values for the indicators will be evaluated. The values of the indicators will be presented as shown in Table 2.2. As an example, this table is filled with fake values for the Mekong River, with the current situation, the situation under climate change, but *without* adaptation, and the situation with adaptation. We only used the A2 scenario here.

Table 2.1 This table shows all possible runs with and without adaptation strategies under the two climate change scenarios A2 and B2, for the years 2039 and 2099.

	2039		2099
A2	2039 A2 no adaptation	A2	2099 A2 no adaptation
	2039 A2 environment		2099 A2 environment
	2039 A2 food		2099 A2 food
	2039 A2 industry		2099 A2 industry
	2039 A2 mixed		2099 A2 mixed
B2	2039 B2 no adaptation	B2	2099 B2 no adaptation
	2039 B2 environment		2099 B2 environment
	2039 B2 food		2099 B2 food
	2039 B2 industry		2099 B2 industry
	2039 B2 mixed		2099 B2 mixed

Table 2.2 This table shows FAKE / made up values for the evaluation of adaptation strategies for the Mekong basin.

Mekong	**indicator**		**measured in**	**current**	**future no adaptation**	**future adaptation strategy**			
				2002	2039 A2	2039 A2 environment	2039 A2 food	2039 A2 industry	2039 A2 mixed
	# affected people (x1000)		number	200	300	300	250	200	250
	Salmon/other fish		+++/---						
	ha upstream forest (x10_6)		number	70	40	50	30	35	45
	ha floodplain forest (x10_6)		number	10	7	8	2	6	6
	ha wetlands (x10_6)		number	6	3	6	2	2	4
Environment	Lateral freedom		%	100%	100%	100%	90%	85%	90%
	Longitudinal freedom		number	3	3	2	3	40	3
	Fertiliser		+++/---	0	-	+	---	-	0
	BOD		+++/---	0	-	+	-	-	-
	NaCl		+++/---	0	-	-	--	--	--
	PCB		+++/---						
	tons of rice (x1000)	per year	number	19,415	33,450	28,000	40,000	33,000	33,450
	tons of maize	per year	number	2,115	5,316	4,500	8000	5,000	5,316
Food	tons river fish caught	per year	number	1,000,000	1,500,000	1,200,000	1,700,000	1,200,000	1,500,000
	average farm income		US $/year	550	500	525	800	800	700
	variation in farm income		US $/year	50	60	60	30	30	45
	# dams		number	3	3	2	3	8	3
Industry	hydropower		MWatt	1000	2000	1500	2000	8000	2200
	# days unnavigable		number	2	4	4	4	2	4

	Good
	Stable
	Decrease
	Bad

A checklist for applying all steps of the framework to a basin is described in Appendix III.

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Appendix I. Environmental Measures and Adaptation Strategies

1. Fish ladder (Side path) for i.e. salmon

The ladders are constructed next to dams and allow free passage for the fish. These ladders make it possible for fish to bypass the obstructions on their way to their spawning grounds (catadromonous and anadromonous species). The goal is that the river will be more habitable for these fish species and that biodiversity will increase.

2. Develop sewage treatment plants

This to reduce the organic pollution from cities into the river and thus lowering the biological oxygen demand (BOD). The oxygen saturation will rise and this positive for the quality of the water. The plant removes suspended solids, harmful chemicals and nutrients. As a result of this the effluent's polluting potential is reduced, allowing more fish and plant life to exist in the river.

3. Develop dikes & protection

Dikes help to protect the inhabitants of the floodplain for high waters. This will improve their security and well-being.

4. Use less fertilizer/less agricultural use of the floodplain

To reduce the inflow of N and P to the river system and reduce the eutrofication of the river. This is positive for the quality of the river. When the agricultural use of the floodplain near the river is less, the inflow of nutrients and pesticides will be reduced. This is positive for the water quality.

5. Construct flood regulation area

These areas will be allowed to flood in times of extreme high levels of water in the river. The level of water in the river will be reduced as a result of the storage of large amounts of water in these areas. Because of this lowering the chance of a breakthrough of a dike will be decreased.

6. Regulate mangrove lodging

To preserve area's of high quality mangrove forests. When the use of products of the mangrove forest is regulated in a sustainable way, the quality of these forest can be maintained. The forest can still be a good habitat for many animals, and it can be used as a for the long term.

7. Protect wetlands (RAMSAR)

Apply RAMSAR regulation to wetland areas in order to create protected areas. These areas may serve as recreation areas.

8. Open reservoir in dry period

Develop balance base discharge by allowing fresh water outflow of a reservoir in the dry season. This may reduce the infiltration of salt and ensures continuation of fresh water flow to wetlands.

Appendix II. Food security related measures and adaptation strategies

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This chapter describes individual measures that can be included in the Food focused adaptation strategy. The assessment indicators to evaluate the impact of these measures have been described in the previous chapter. It might be clear that some of the adaptation measures are more relevant to a particular basin than others.

II.1 Farmers measures

II.1.1 Irrigation and rainfed related measures

A set of field scale water management measures are available as adapt strategies to climate change and climate variability. One measure that is receiving often substantial emphasis is the shift from more traditional irrigation systems as flooded and border techniques towards pressurized systems as sprinkler or drip. It has become evident over the last decade that these techniques can indeed improve water productivity as non-beneficial evaporation from bare soil, open water and weeds can be reduced, but since in water scarce areas reuse of other field-scale "losses" is normal practice, real water savings are limited. Some guestimates are that 10-25% of the total evaporation during a growing season is non-beneficial. Better distribution within a field and salinity control by more accurate water deliveries are factors that should be taken into consideration as well. A factor often neglected is that farmers will not accept a reduction in water delivered after investments in pressurized irrigation systems leading to, at least, similar deliveries but less return flows.

Deficit irrigation

Deficit irrigation is in many cases a good measure to increase the productivity of water, but reduces the yield per hectare and is therefore only practiced by farmers whose land is not limiting. Obviously, water managers can try to force deficit irrigation by limiting water allocation, a normal practice of the warabandi systems in India and Pakistan.

Irrigated to rainfed or rainfed to irrigated

Along the same line is the transition from irrigated agriculture to rainfed systems if water is clearly limited and not land. Contrary, if land is limited and water not a shift from rainfed agriculture to irrigation can be considered as an adaptation measure. In the most extensive case this is known as crop saving irrigation where only one or two irrigations are applied to help the crop to survive a drought period during the growing season.

Water harvesting

Water harvesting is often used under conditions with erratic rains, a short rainy season and a high evaporation. Typical measures to deal with such circumstances are: in situ water conservation (constructing terraces and/or contour strips, growing crops in pits etc.), spate irrigation, or creating storage for supplementary irrigation during dry spells.

Maintaining permanent soil cover / no tillage

Keeping a permanent soil cover and zero or minimum tillage are measures that are often used as part of conservation agriculture that reduce soil evaporation and runoff.

II.1.2 Drainage

In cases where more precipitation is expected and crops can suffer from too much water (in reality deficit oxygen) drainage could be considered as an adaptation measure. Vertical or horizontal drainage systems as well as open or closed are some of the measures. Removing impermeable disturbing soil layers can also improve drainage conditions.

Drainage can also be used as an option to improve agricultural production in cases where groundwater levels are rising as a result of irrigation and salinization is a threat.

II.1.3 Cropping patterns

An increase in total cropped area is one of the most practiced measures to increase food security. Obviously, the extent of this depends on water and land availabilities and should therefore be considered in combination with adaptation measures mentioned under "irrigation and rainfed deliveries".

Change in crop

A change in crop can increase food security in several ways. Changing from a high water demanding crop to a lower one is an adaptation strategy if water is becoming scarcer. It could also be considered to change from food crops to cash crops which can be an indirect way to enhance food security.

Change in crop variety

A change in crop variety, in combination with intensification of the cropping pattern (more crops per year), and an areal increase of cropped areas, is generally seen as the success of agriculture over the last decades. Varieties have been introduced that can produce twice or three-times the yield of older varieties. A drawback of these new varieties is sometimes that field scale management, such as pesticide control and nutrient status should be enhanced as well, putting a lot of pressure on farmer's investments and thus risk-taking.

Increase cropping intensity

Changing planting date

Changing the planting date of a crop or a crop variety may be a necessary adaptation to climatic changes.

Increasing crop diversity

Increasing crop diversity can spread the risk for farmers in adaptation to a more variable climate that causes unreliable weather conditions.

II.1.4 Salinity control

Salinity is becoming a major problem in arid and semi-arid regions and alarming messages that 25-50% of agricultural areas in these regions are affected by salinization or expected to become soon. Some of the measures defined before can accelerate salinization if not carefully implemented (deficit irrigation), others can reduce salinization hazard (drainage).

II.1.5 Intensification

Many adaptation strategies to climate change and climate variability are possible under the general notion of intensification. A range of options are available such as land leveling, weed control, pest control, enhancing soil fertility and tillage practice. Crop yields and water productivity can increase 2-5 times, but requires in general higher investments.

II.2 Water Management

II.2.1 Water allocation

The allocation of water to irrigated agriculture is a tool available to water managers as an adaptation measure to changes in climate and climate variability. Improved water allocation should be considered spatially as well as temporally. A better match between crop water requirements and water deliveries is an example of the latter, while distributing water to areas with higher value crops or better soil conditions are examples of spatial distribution water allocation.

II.2.2 Water storage capacity

Increasing water storage capacity is a very efficient adaptation strategy as extremes are likely to occur more frequent under climate change. This increased storage capacity can be implemented by dams, small scale water storage options or by using groundwater storage capacity.

Dams and especially large dams have been under debate over the last decade and the World Commission on Dams made it clear that carefully planning of dams is necessary to assess also the disadvantageous of dams. A few cases are known in the US where the negative impact of existing dams was so big that apparently the only solution was to remove them.

Storage in smaller reservoirs is often initiated by a group of farmers or a village. Negative impacts of big dams, especially environmental concerns, are overcome with these smaller storage reservoirs. It might be clear that the main objective of these smaller reservoirs is to support some short-term dry spells within a year, but that for droughts over longer time spans, as expected under climate change, these smaller reservoirs have only limited use.

Groundwater is often seen as one of the major sources that can be used as adaptation measure to increased variability in water availability. Careful planning is however essential but at the same time very difficult as groundwater is not observable easily and extractions are difficult to control. In the ideal situation groundwater can be exploited during dry periods as long as in wetter years recharge is guaranteed. In reality farmers investing in pumps are not willing to use their investments only during dry periods resulting in unsustainable use of groundwater resources. Stringent legislation and control seems to be only a feasible option in the developed world.

II.2.3 Re-use of waste water

If the pollution loads of water used by industries and urban areas is reduced, it could be re-used as irrigation water. The fertilizer value of the effluent is almost as important as the water itself. The nutrient concentration of treated wastewater could provide a large part of the nutrient requirements for agricultural production. However, treating wastewater is expensive and in a lot of developing countries wastewater is drained away without any treatment. If wastewater is used for irrigation while not treated properly it is a risk for human health. Until now the use of treated wastewater for food production is not practiced on a large scale, but in future it might very well be an additional source of water for agricultural production.

II.2.4 Desalination

Desalination is in principle only an option for water users close to a sea or salt lakes. Saline drainage water might also be re-used by desalination process this is only practiced where a reasonable volume and a constant supply is guaranteed. Nowadays about 12,000 desalting plant are active around the world, cleaning a total amount of around 23 MCM per day. Water from desalination plants is still very expensive and, depending on water quality used, water quality to be provided, technique used, energy prices, around $1 to $2 per liter. However, a newly constructed plant in Florida offers desalined water for around $0.50 but since this plant has special features (very low energy prices, constructed in combination with a power plant, lower salinity levels than seawater), a price around $1 as planned for other new projects is a more realistic one.

This price is clearly too expensive to consider desalined water as a source for agricultural purposes.

II.2.5 Fog collection

Since about 15 years some attempts have been made to collect water from fog by an artificial mesh and piping system (Cereceda et al., 1992). Although some successful applications have been found in coastal areas and interior mountain regions, application at bigger scales is unlikely. Some of the limitations are that fog should occur during extensive periods, average costs are high (although in some cases lower than trucked water supply), high initial investment costs, storage capacity during periods without fog required and maintenance. In practice fog collection might be an option for some specific regions and mainly for domestic water supply.

II.3 Policy Makers

II.3.1 Water pricing

Water pricing has been seen and is still considered by a large group of policy makers as the main solution and adaptation strategy to force people to save water. The logic is that water should be treated similar as other goods to balance supply and demand. However, the last decade doubts have been expressed over this way of thinking, especially if it concerns water for agriculture in the developing world. Main reasons are that water is so cheap that even an increase of 100% is still not an incentive to use less water and the political will to increase prices and thus increase costs for farmers (the majority of the population in the developing world) does not exist.

An also practical reason as how to implement, control and enforce water pricing is a major problem in the developing world.

II.3.2 Water rights

As an alternative to water pricing water rights have been promoted. As an adaptation strategy to climate change and climate variability this includes the right to a certain amount of water as a function of total water available. This means that farmers will know in advantage that, given the total amount of water available, how much they are entitled to receive. Included in these water rights is the option to treat water, so farmers can use this as a clear adaptation strategy as during abundant water conditions they can use their water for themselves, but during water shortages they can sell their share to other users having higher-value purposes (crops or even other sectors). Similarly to water pricing legislation and especially enforcement is an issue of concern.

II.3.3 Education

Intensification and improved crop management by farmers is a key adaptation strategy that can be stimulated by policy makers in terms of research, training, extension services, and improved access to information related to water and agriculture. The direct impact is somewhat difficult to measure, as investments will take five to ten years before results can be observed.

Weather forecasting

A good system of weather forecasting can provide farmers with valuable information to optimize their agricultural practices. Reliable weather forecasts can help farmers with choosing the right day to plant and harvest their crops as well as optimizing their irrigation schedule.

Credit facilities

Credit and banking facilities can help farmers to spread the risk of a higher variability in farm income, due to a higher variability of climatic circumstances.

Insurances

In many countries there are already insurances that cover the consequences of extreme weather events. With a higher variability in climate this may become more important in future.

Appendix III. Checklist for applying the decision framework

An evaluation of different management alternatives (strategies) of the river basin is performed in the following steps:

III.1 General description

Describe all drivers (CC/CV scenarios, Population growth, economic growth) (This has been done quite substantially in the first draft basin reports)

Describe pressures in terms of issues and problems of the basin related to water resources management. (This has been done quite substantially in the first draft basin reports)

Development of scenarios: A2, B2 CC/CV and the food requirements (FAO)

Setup up of Hydrological models and food production models

III.2 Assessment study

Run the hydrological models for the current and future situation and describe the main hydrological changes in terms of: Water availability, discharges, aridity, etc.

Check indicator sets. Add indicator when it appears that not all issues are covered/measured for the basin (under one the three issues environment, food, industry)

Check whether the list of environmental, food and industrial measures cover all possible measures in your basin.

Current situation: Apply values to the different indicators for the present using either the models or expert judgment

Future without adaptation: Run the simulation models *without* adaptation strategies and value the indicators direct from the modeled data or use expert judgment.

Specification of four different sets of adaptation strategies, each of them in favor of the different issues (Environment, Food, Industry) and develop one mixed strategy comprising all three aforementioned issues

Future (A2) with adaptation: Run the simulation models with the different adaptation strategies and assess the effects on environment, food and industry under scenario A2. Use expert judgment when the models can not help valuing the indicators

Future (B2) with adaptation: Run the simulation models with the different adaptation strategies and assess the effects on environment, food and industry under scenario B2. Use expert judgment when the models can not help valuing the indicators

Evaluate and describe the effects of different strategies under different CC scenarios in matrix.

Extra assessments for *food*: Try to valuate the costs in U$ for the different adaptation strategies and try to valuate the costs due to damage to food production in U$. IVM will help setting up a framework for doing this exercise.